

### In the Specification

Please amend the entire specification as follows. A clean copy of the specification is attached as Appendix A.

**~~Blue Light emitting, ladder type~~ Ladder-type and Blue Light-Emitting Polymer  
with Excellent Thermal Heat Stability**

### FIELD OF THE INVENTION

The present invention relates to luminescent ~~polymer~~ polymers, specifically ladder-type and blue light-emitting polymer ~~polymers~~ with excellent thermal heat stability, which are prepared ~~polymerization, after grafting by~~ polymerization of blue luminescent ~~to backbone polymers or after substituting luminescent monomers to styrene derivatives monomer~~ or grafting blue luminescent monomer.

### PRIOR ART

~~Polymers are generally classified as non-conductive and are not used as the electronic materials. Polymers have been generally classified as insulators. Recently, Development of conducting polymers such as polyaniline, polypyrrole and polythiophene have been developed, which provided excellent materials with the provide conductivity as same high as metals, light weight, and processability metal. These polymers have advantages over metal in aspects of light weight and processability.~~

~~The conjugated~~ Conjugated polymers with ~~the~~ electrical and optical characteristics have been ~~are used for~~ anti-static materials, sensors, electrodes, transistors, light-- emitting materials, solar cell, smart cards, electronic newspapers, and other display devices. ~~The luminescence polymer materials have~~ Luminescence polymers have been extensively developed extensively since the electroluminescence with poly(1,4-phenylenevinylene) was reported in Cambridge group in 1990 (Burroughes, J. H.; Bradley, D. D. C.; Brown,

A. R.; Marks, R. N.; Mackay, K.; Friend, R. H.; Burn, P. L.; Holmes, A. B. Nature 1990;347:539). Features of luminescence polymers ~~The materials are,~~ in comparison with the inorganic materials, light weight, thin, self-luminescent, ~~mobile with~~ of low voltage, ~~and have~~ threshold voltage. These polymers also provide fast switching velocity, easy processability, low production cost, low dielectric constant, and most of all, prospect of various uses, making them as the light emitting materials for the information and communication technology of next generation. They provide the advantage of easy fabrication and controllable electrical and optical properties by the modification of their molecular structures, which allow these polymers to be promising candidates of light-emitting materials for information and communication technology of the next generation.

~~The~~ A blue luminescent polymer employs ~~uses~~ aromatic groups ~~compounds~~ such as fluorene or spiro-fluorene such as conjugated polymers ~~of the backbone polymers.~~ Examples ~~are as~~ described in U.S. Patent Nos. of 5593788, 5597890, 5763636, and 5900327. In U.S. Patent No. 5998045, the luminescent polymers ~~materials are were~~ prepared by the use of polymers ~~copolymerized~~ copolymerization of fluorene and anthracene. The copolymers ~~by the~~ of fluorene and aromatic compounds (for example, carbazole) ~~are were~~ reported in German Patents Patent Nos. ~~of~~ 198 46 766, 198 46 767, and 198 46 768. In U.S. Patent No. 6395410, ~~making an~~ electroluminescence devices were prepared with ~~is reported by mixing the~~ luminescent materials and transparent polymers, ~~with low absorption in the visible light regions (such as polycarbonate, polystyrene, polymethacrylate, polyvinylcarbazole).~~ Recently, application research ~~is under way for the organic semiconductor using a thin film (App. Phys. Lett. 80(6), 1088).~~

~~Much effort is~~ ~~Much improvements are needed as yet in the~~ to achieve enhanced durability and brightness of the blue light-emitting polymers ~~when they are applied to the~~ for their use in luminescent devices. ~~The devices, the main reason being due to~~ because ~~of their poor~~ thermal stability. Heat causes molecular movement ~~movements of polymers~~ and generates fine particles or coagulates ~~the polymers~~. Heat generation ~~Generation of~~ heat increases in proportion to the ~~using~~ period of working time of the electroluminescence devices, ~~decreasing their durability when the glass transition temperature and melting temperature are below 300°C.~~ The existing light-emitting polymers have the glass transition temperature at around 100 °C (Macromolecules; 1988; 31(4); 1099-1103) causing such ~~the above~~ problems.

### SUMMARY OF THE INVENTION

Therefore, the inventors of the present invention intended to prepare the blue luminescent polymers with high melting point and ~~heat stability~~ with excellent thermal stability.

As a result, ~~as the ladder-type blue light-emitting polymers that can completely satisfy~~ solve the said problems, the are provided herein. ~~present invention comprises either~~ polymerizing the polymers after grafting the These polymers can be formed by polymerization of blue luminescent monomers or grafting blue luminescent monomers ~~light-emitting monomers to their backbone or polymerizing styrene monomers~~ after addition of fluorine group to them.

### BRIEF DESCRIPTION OF THE DRAWINGS

~~Fig.~~ Figure 1(a) is the conceptual picture of a conventional blue light-emitting polymer.

~~Fig.~~ Figure 1(b) is the conceptual picture of a ladder-type blue light-emitting polymer.

~~Fig.~~ Figure 2 shows synthetic scheme of the ladder-type blue light-emitting polymer.

~~Fig.~~ Figure 3 shows the UV-VIS spectra.

~~Fig.~~ Figure 4 shows the photoluminescence spectra.

~~Fig.~~ Figure 5 shows the TGA of P1.

Figure 6 shows the TGA of P2.

### DETAILED DESCRIPTION OF THE INVENTION

The present invention provides ~~the preparation of the heat stable and blue thermally stable and blue light-emitting polymers and the preparation therefor.~~ Novel luminescent polymers with ~~the a~~ ladder-type structure are ~~proposed in order to make~~ described, which are thermally high heat stable polymers differing from the existing luminescent polymers the the have a high glass transition temperature around 100 °C. These polymers have high glass transition temperature, above 400 °C, and high temperature of 5%-weight loss, above 450 °C, and are is easily-soluble in the organic solvents solvent for thin film applications. In these polymers, polystyrene, serving as backbone, enabling the production of thin films. The backbone polystyrene is transparent in the visible region, increases compatibility with other polymers, inhibits molecular movement and increases thermal the heat stability.

The conventional polyfluorene and polyaryl polymers have the structure of (a) as shown in Figure 1, and are movable at a higher the figure 1. ~~Their molecular movement at a higher temperature is active, making it difficult to have the glass transition temperature above 100 °C.~~ The m ladder-type polymers of the invention have a structural composition as shown in Figure 1 (b). ~~In Figure 1(b) where~~ block A is light-emitting part, ~~while~~ and block B is polystyrene ~~that.~~ Polystyrene has excellent optical properties,

high thermal ~~heat~~ stability and inhibits molecular movement. The polystyrene block is readily dissolved in solvent, and allows easy fabrication ~~the solvents readily, making it~~ easy to fabricate thin film.

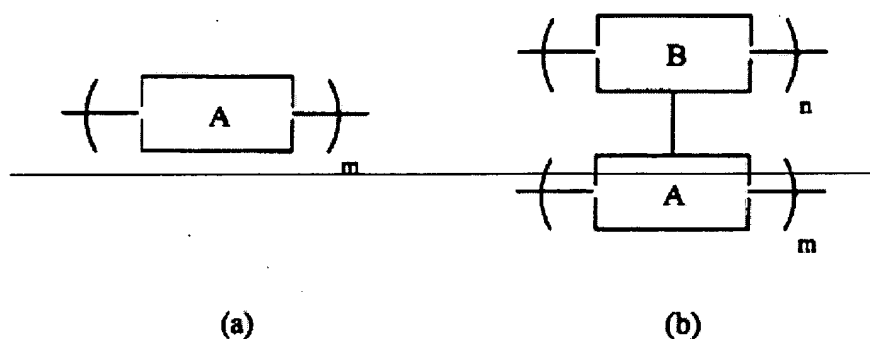


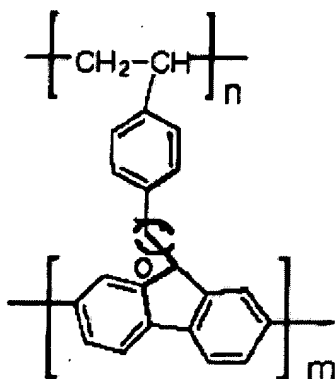
Figure 1, ~~The conceptual picture of~~ Figures 1(a) and 1(b) show a conventional blue light-emitting polymer (a) and a ladder-type blue light-emitting polymer (b)

~~Therefore, the present invention provides the blue light-emitting polymer represented in he figure 1(b).~~

The polymers as shown in Figure 1(b) can have different formula, which are described below:

~~Wherein,~~ The polymer of Figure 1(b), where A is selected from polyfluorene, polythiophene, polypyrrole, polycarbazole, polyphenylene, polyaniline, and polypyridine; B is selected from polystyrene, polypyrrol, polythiophene, polycarbonate, polyphenylene, polyaniline, polypyridine, and polycarbazole; n is an integer of 5 to 100; and m is an integer of 2 to 100. And, the The blue light-emitting polymer can be represented by the following formula 1.

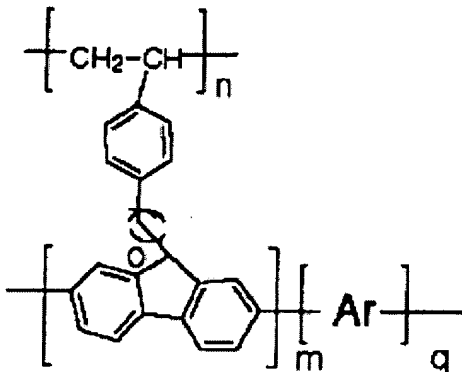
~~Wherein A is polyfluorene; B is polystyrene; n is an integer of 5 to 100; and m is an integer of 2 to 100.~~



[Formula 1]

The polymer of Figure 1(b), where A is polyfluorene; B is polystyrene; n is an integer of 5 to 100; and m is an integer of 2 to 100.

And, the present invention provides the blue light-emitting polymers containing Ar compounds additionally represented in the formula 2;



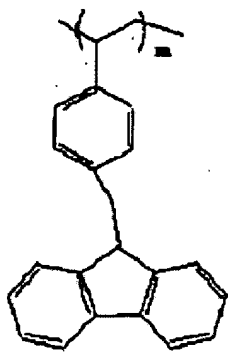
[Formula 2]

~~Wherein~~ wherein Ar is aromatic compounds a compound such as fluorene, fluorene derivatives, benzene, benzene derivatives, thiophene, thiophene derivatives, carbazole, carbazole derivatives, pyridine or pyridine derivatives; ~~Preferable, preferably,~~ B is polystyrene with atactic or syndiotactic structure as shown in the formula 1 or 2.

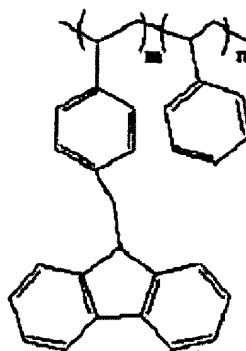
The ladder-type blue light emitting polymers described above can be synthesized in various methods. Two exemplary synthetic schemes for the ladder-type blue light-emitting polymer are shown in Figure 2.

The first method comprises eliminating a hydrogen atom from C<sub>9</sub> position of fluorene or dibromofluorene using n-butyl lithium in tetrahydrofuran, grafting polyvinyl benzene chloride to it, and polymerizing aryl groups with nickel or iron catalyst (Figure 2, upper scheme).

The second method comprises substituting chloride atom of vinyl benzene chloride with fluorene, polymerizing the styrene part, and polymerizing fluorene with the use of nickel or iron catalyst. Other method includes polymerizing vinylfluorene, [formula 3], or copolymerizing styrene with vinylfluorene to make a polymer of [formula 4], and polymerizing fluorene groups (Figure 2, lower scheme).

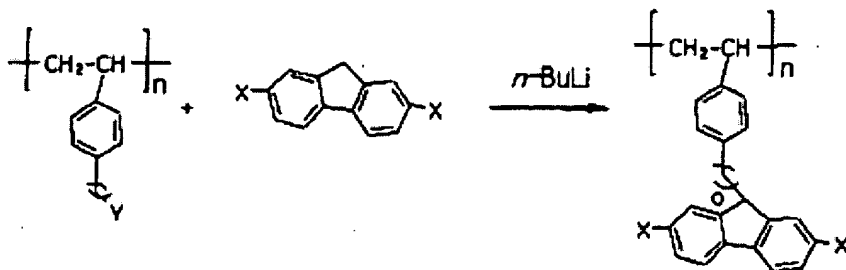


[Formula 3]



[Formula 4]

1.



2.

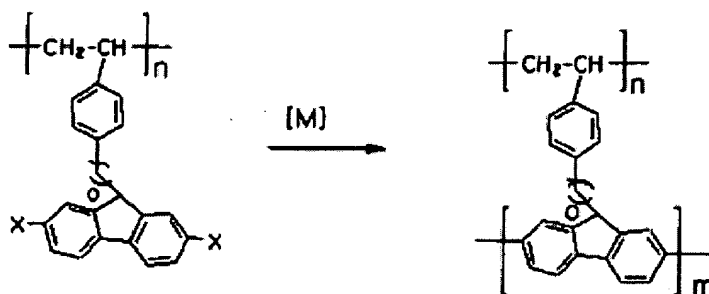


Figure 2: ~~synthetic scheme of the ladder-type blue light emitting polymer.~~

In the UV Visible spectrum of the polymer P1,  $\lambda_{\text{max}}$  is obtained at 362 nm (Fig. 2). For P2,  $\lambda_{\text{max}}$  is also obtained at 362 nm. The emissions of P1 and P2 are in the region of 450-540 nm (Fig. 4). The temperatures of 5% weight loss of P1 and P2 in TGA are observed at 475 °C and 448 °C, respectively (Fig. 5 & 6). Accordingly to DSC, the glass transition temperatures of p1 and P2 are at above 400 °C and the melting points are not observed.



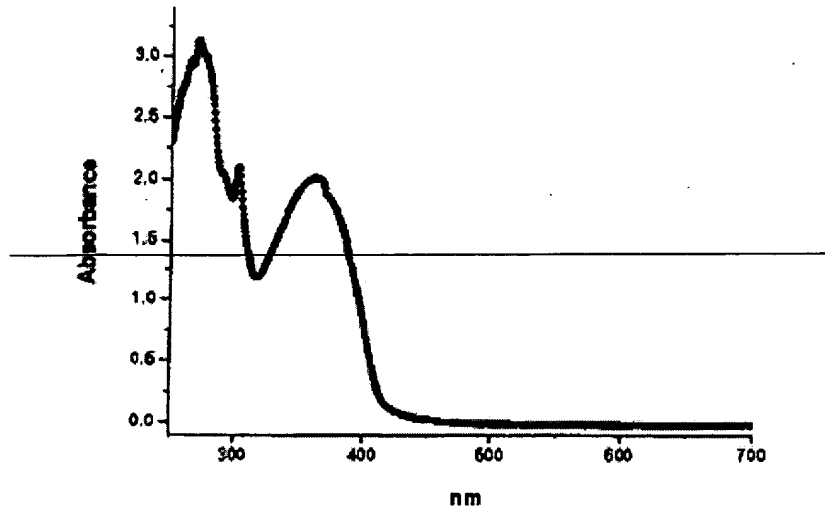


Figure 3. UV-VIS spectrum

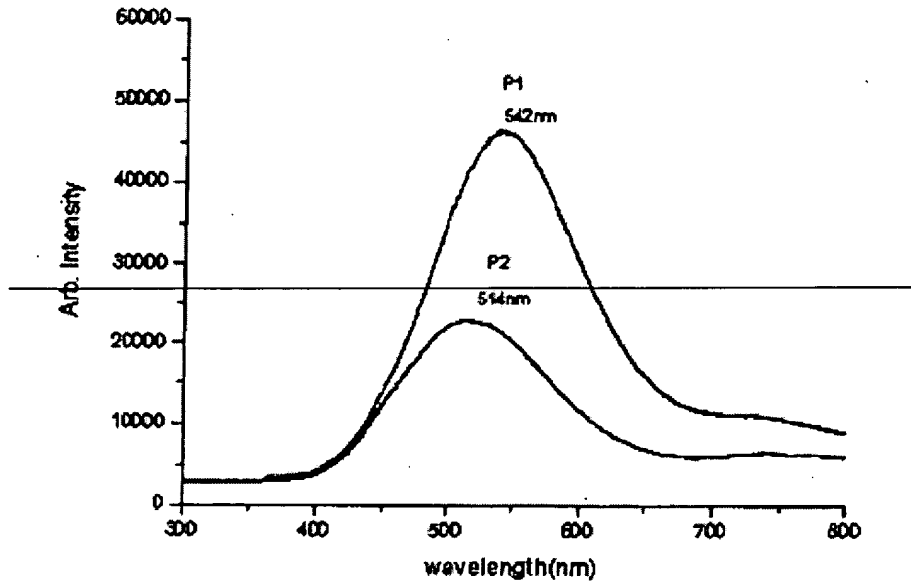


Figure 4. Photoluminescence spectrum

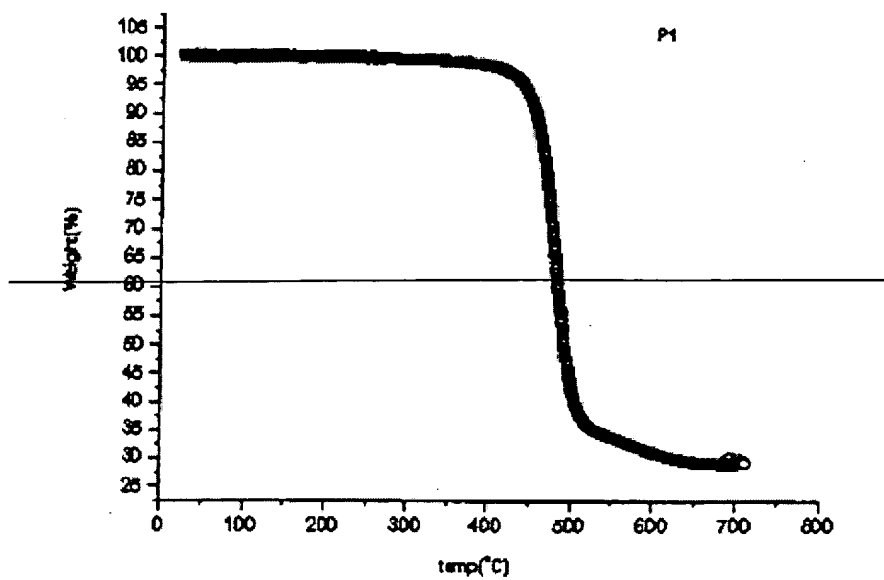


Figure 5. TGA of P1

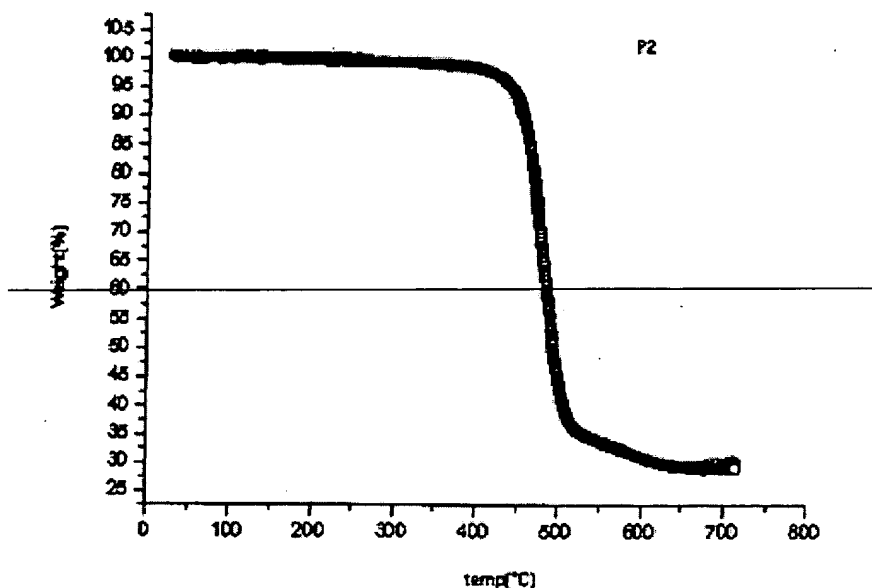


Figure 6. TGA of P2

The polymers synthesized, as described above, have phase stability and thus would have a long life while maintaining the efficiency of light emission. In fabricating devices, the polymers can be coated on an electrode by spin coating or ink jetting. They can also increase the compatibility with the polymers of good optical properties (for example, polycarbonate, polymethylmethacrylate and polystyrene). The polymers can be copolymerized with aromatic compounds such as fluorene, benzene, thiophene, carbazole, pyridine, styrene and their respective derivatives.

The analytical instruments used are as following. The gel permeation chromatography of Viscotek Co. was used after calibration with polystyrene. The solvent used was tetrahydrofuran (THF). JASCO V-570 for UV Visible spectrum and Varian Unit Inova 200 (200MHz) for  $^1\text{H}$  MNR were utilized. TGA was determined by TGC 7/7 of Perkin Elmer Co. under  $\text{N}_2$  atmosphere, increasing the temperature by  $20^\circ\text{C}/\text{min}$ .

~~Photoluminescence spectra was obtained by Spectrapro 275i & 300i spectrometer of Acto Co. equipped with CCD camera, using W lamp as a light source.~~

The following examples further illustrate the present invention in detail but do not limit the scope thereof.

Example 1: 9-Vinylbenzyl fluorene.

Fluorenyl lithium was prepared by reacting fluorene (10.0 mmol) with t-butyl lithium (1.7 M in *n*-pentane, 10.0 mmol) in THF (10 mL) at -78 °C for 2 hours. Fluorenyl lithium was slowly added to vinyl benzene chloride (10 mmol) in THF solution at -78 °C and reacted with stirring for 16 hours. Water (100 mL) and ether (100 mL) were added and stirred. Organic layer was extracted, dried and recrystallized to obtain needle shape and ivory colored solids solid.

<sup>1</sup>H-NMR (200 MHz, CDCl<sub>3</sub>): 7.77 (2H, d, Fu-H), 7.39-7.20 (10H, m, Fu-H, Bn-H), 6.80-6.66 (1H, q, Vy-H), 5.80-5.70 (1H, d, Vy-H), 5.27-5.21 (1H, d, Vy-H), 4.23 (1H, t, Fu-H), 3.10 (1H, d, Bz).

Example 2: Polyvinylbenzyl dibromofluorene

Under N<sub>2</sub> atmosphere, polyvinylbenzyl chloride (1.57 g, M<sub>w</sub> 55,000) is dissolved in THF (20 mL). Dibromofluorene (3.24 g) was dissolved in THF (50 mL) and cooled to -78 °C. To this solution, 4 mL of n-butyl lithium (2.5 M, *n*-hexane solution) was added and the resulting solution was added slowly to the above polyvinyl benzene chloride solution. The mixture was stirred at room temperature for 6 hours and water was added. The product was extracted with ethyl ether (200 mL) and dried under vacuum. Obtained product was yellow solid. M<sub>w</sub>: 272900. MWD: 5.71. UV-Vis (λ<sub>max</sub>, THF): 298 nm.

Example 3: Polyvinylbenzyl fluorene

Under N<sub>2</sub> atmosphere, Polyvinylbenzyl chloride (1.57 g, M<sub>w</sub> 55,000) was dissolved in THF (20 mL). Fluorene (1.67g) was dissolved in THF (50 mL) and cooled to -78 °C. To this solution added was 4 mL of n-butyl lithium (2.5 M, *n*-hexane solution). The resultant solution was added to the above polyvinyl benzyl chloride solution. The mixture was stirred for 6 hours at room temperature and water was added. The product was extracted with ethyl ether (200 mL) and dried under vacuum. Yellow solid was obtained.

M<sub>w</sub>: 68160. MWD: 2.96. UV-Vis ((λ<sub>max</sub>, THF): 302 nm.

Example 4: Polyvinylbenzyl-polyfluorene (P1)

Under N<sub>2</sub> atmosphere, polyvinylbenzyl fluorene (1.57 g, M<sub>w</sub> 55,000) and dihexylfluorene (3g) were dissolved in chloroform (20 mL). To the solution FeCl<sub>3</sub> (5g) was added and stirred for 4 hours at room temperature. To the mixture methanol was added and the produced precipitates were filtered. The obtained solids were dissolved in THF and the insoluble solids were discarded. The THF solution was dried under vacuum, and yellow solid was obtained.

M<sub>w</sub>: 79040. MWD: 2.94. UV-Vis ((λ<sub>max</sub>, THF): 362 nm. PL (λ<sub>max</sub>, THF): 542 nm. TGA (5%, °C): 475, Glass transition temperature(°C): 421.8.

Example 5: Polyvinylbenzyl-polyfluorene (P2)

Under N<sub>2</sub> atmosphere, polyvinyl benzyl dibromofluorene (1.57g, M<sub>w</sub> 55,000) and dihexylfluorene(3g) were dissolved in chloroform(20 mL). To the solution FeCl<sub>3</sub> (5g) was added and stirred for 4 hours at room temperature. To the mixture methanol was added and the produced precipitates were filtered. The obtained solids were dissolved in

THF and the insoluble solid was discarded. The THF solution was dried under vacuum, and yellow solid was obtained.

$M_w$ : 132200. MWD: 2.07. UV-Vis ( $\lambda_{max}$ , THF): 362 nm. PL ( $\lambda_{max}$ , THF): 514 nm.

TGA (5%, °C): 448, Glass transition temperature (°C): 404.4.

**Example 6: Polyvinylbenzyl-polyfluorene (P3)**

Under N<sub>2</sub> atmosphere, polyvinyl benzyl dibromofluorene (1.57 g,  $M_w$  55000) and dihexylfluorene (3 g) were dissolved in benzene (20 mL). To the solution Pd(PPh<sub>3</sub>)<sub>4</sub> (5 g) was added and refluxed for 6 hours. To the mixture, methanol was added and the resultant precipitates were filtered. The obtained solid was dissolved in THF, and the insoluble solid was discarded. The THF solution was dried under vacuum, and yellow solids were obtained.

$M_w$ : 159300. MWD: 4.34. UV-Vis ( $\lambda_{max}$ , THF): 330 nm. PL ( $\lambda_{max}$ , THF): 445 nm.

**Example 7: Polyvinylbenzene-poly(fluorene-co-thiophene) (P4)**

Under N<sub>2</sub> atmosphere, polyvinyl benzyl dibromofluorene (500 mg,  $M_w$  55000) and 3-octylthiophene (2 g) were dissolved in chloroform (20 mL). To the solution FeCl<sub>3</sub> (2.5 g) was added and stirred for 4 hours at room temperature. To the mixture, methanol was added and the produced precipitate was ~~precipitates were~~ filtered. The obtained solid was dissolved in THF, and the insoluble solid was discarded. The THF solution was dried under vacuum, and ~~obtained~~ yellow solid was obtained.

$M_w$ : 8911. MWD: 3.14. UV-Vis ( $\lambda_{max}$ , THF): 405 nm. PL ( $\lambda_{max}$ , THF): 544, 682 nm.

TGA (5%, °C): 280. Glass transition temperature (°C): 384.8

**Example 8: Syndiotactic polyvinylbenzyl fluorene**

Under N<sub>2</sub> atmosphere, 1-vinyl-4-(1-fluorenyl)methylbenzene (0.52g) was added into a flask and dissolved in toluene (20 mL). To the solution, 12.1 mmol of MAO (2.43 mg, 5 mL) was added slowly and stirred for 30 minutes. 10 mmol of CpTiCl<sub>3</sub> (2.19 mg) was dissolved in 1 mL of toluene and added slowly to the solution at room temperature. After addition, the mixture was stirred for one hour at room temperature and poured into a 200 mL of acidic methanol to obtain solid product. The product was washed with methanol, and dried under vacuum for several hours and 0.3 g of copolymer was obtained. M<sub>w</sub>: 2500.

**Example 9: Syndiotactic polyvinyl benzyl fluorene-co-styrene (P5)**

Under N<sub>2</sub> atmosphere, styrene (2.1 g) and 1-vinyl-4-(1-fluorenyl)methylbenzene (0.52 g) were added into the flask and dissolved in toluene (20 mL). To the solution, 12.1 mmol of MAO (2.43 mg, 5mL) was added slowly and stirred for 30 minutes. 10 mmol of CpTiCl<sub>3</sub> (2.19 mg) was dissolved in 1mL of toluene and added slowly to the above solution at room temperature. After addition, the mixture was stirred for 2 hours at room temperature and poured into a 200 mL of acidic methanol to obtain solid product. The product was washed with methanol and dried under vacuum for several hours. ~~hours and~~ 2.5 g of **P5** was obtained. M<sub>w</sub>: 8,000.

**Example 10: Syndiotactic polystyrene-polyfluorene (P6)**

Under N<sub>2</sub> atmosphere, P5 (500 mg. M<sub>w</sub> 8000) was dissolved in chloroform (20 mL). To the solution, FeCl<sub>3</sub> (2.5 g) was added and stirred for 4 hours at room temperature. Methanol was added to the mixture and the precipitates were filtered. The solid precipitate was dissolved in THF and the insoluble solid was discarded. The THF solution was dried under vacuum, and yellow powder was obtained.

$M_w$ : 4802. MWD: 2.42. UV-Vis ( $\lambda_{max}$ , THF): 353 nm, PL ( $\lambda_{max}$ , THF): 46 nm, TGA (5%, °C): 232.8, Glass transition temperature (°C): 413.5.

The polymers exhibited glass transitions ( $T_g$ ), 422 °C for **P1**, 404 °C for **P2**, and 414 °C for **P3**, and no melting endotherms were found out. Syndiotacticity contributes the high glass temperature of **P3** in spite of low molecular weight. Thermal decomposition temperatures at 5%-weight loss ( $T_d$ ), 475 °C for **P1**, 448 °C for **P2**, and 233 °C for **P3** were observed. The fluorescence peaks of **P1**, **P2**, **P3** were observed at 401 nm, 416 nm and 415 nm, respectively. For the emission spectrum of **P3**, no shoulder or peak regarding of aggregation of polyfluorene was observed.

Syndiotacticity, due to alternative configuration of fluorene, prevents a large Stoke's shift of the luminescence spectrum.

The polymers synthesized, as described above, have high thermal stability and a long life time maintaining the efficiency of light emission. ~~In fabricating~~ To fabricate devices, the polymers can be coated on an electrode by spin-coating or ink-jetting. They can also increase the compatibility with the polymers of good optical properties (for example, polycarbonate, polymethylmethacrylate and polystyrene). The polymers can be copolymerized with aromatic compounds such as fluorene, benzene, thiophene, carbazole, pyridine, styrene and their respective derivatives.

The analytical instruments used are as following. Molecular weight was determined by GPC analysis (Viscotek Co.) using polystyrene standards and THF as solvent at 40 °C. JASCO V-570 and Varian Unit Inova 200 (200 MHz) were used to measure UV-visible and  $^1\text{H}$ -NMR spectra, respectively. The thermal data of the ladder-polymers were obtained on nitrogen atmosphere at a rate of 20 °C/min by using Perkin-Elmer's



TGC 7/7. Fluorescence spectra were obtained with SLM-AMINCO 4800 spectrofluorometer, in which Rhodamin was used as quantum counter.

### **EFFECT OF THE INVENTION**

A series of 2-dimensional ladder-type polyfluorenes was prepared by introducing atatic or syndiotactic polystyrene as the backbone. The ladder-type polyfluorenes have a high  $T_g$  more than 400 °C and excellent thermal stability. No remarkable aggregation of interchains was observed in the ladderized polyfluorene having syndiotactic polystyrene as the backbone. Accordingly, the polymers can be utilized as blue light-emitting applications such as display devices, household electric appliances and cellular phones.

~~As described in details above, the blue light emitting polymers have a high glass transition temperature and a high temperature of 5% weight loss. Accordingly, the polymers can be utilized as blue light emitting materials in the display devices as well as light emitting cases of household electric appliances and light emitting cases of cellular phones.~~